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ABSTRACT

Possible relationships between industrial innovation and science education are discussed, focusing on three systems for studying the process of development and identifying certain determining factors. The purpose of the approach is to identify the salient characteristics of the industrial world, technological development, and science teaching by examining the tentative groupings of social innovations, with their successes and failures, and, by so doing, to arrive at a new project and a new scale of values. Discussions are presented in five sections. Following introductory material in section 1, industrial change is considered in section 2, focusing on the innovation process (including the function of information, the Gruber and Marquis model, practical implications, and function of the entrepreneur), the origin of inventions, and a typology of innovation. Technology of the 1990s (considering energy, the environment, biotechnology, and the redeployment of technology) is discussed in section 3. The process of creativity, profile of the creative individual, and the development and influence of the computer as they relate to science teaching are considered in section 4. The final section, a scenario that suggests a thorough reorganization of science education from a global perspective, outlines and discusses the characteristics of this holistic approach (the macroscole). The appendix contains a summary of research on characteristics of creative individuals and techniques for stimulating creativity. (JN)

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MACROSCOLE

A Holistic Approach to Science Teaching

A Discussion Paper
by Marcel Risi

October 1982

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TABLE OF CONTENTS

FOREWORD 5

I. INTRODUCTION: A NEW FORM OF DIALOGUE 7

II. INDUSTRIAL CHANGE 11

The Innovation Process 13
The Function of Information 13
The Gruber and Marquis Model 16
The Practical Implications 17
The Function of the Entrepreneur 18

The Origin of Inventions 21
Decentralization of Authority 21
Capacity to Absorb Mistakes 21
Flexible Communications Network 22
Management of Human Resources 22

A Typology of Innovation 24

III. THE TECHNOLOGY OF THE 1990s 29

Energy 29

The Environment 31

Biotechnology 32

The Redeployment of Technology 33

IV. THE TEACHING OF SCIENCE 37

The Process of Creativity 38
The Profile of the Creative Individual 39
The Two Routes 39

The Development and Influence of the Computer 41

V. ONE SCENARIO: THE MACROSCOLE 45

The Ecosociety 46
Ecotechnology 46
Ecoeducation 47

The Macroscole 48

A Final Thought 49

TABLES

Table I - The Major Stages of Innovation 15
Table II - The Innovation Process 16
Table III - Measurement of the Creativity of Companies 38
Table IV - The Elements of Creativity 40

APPENDIX 51

NOTES 57

BIBLIOGRAPHY 59

FOREWORD

This paper is the fifth in a series of discussion papers prepared for a study of Canadian science education; the study was undertaken by the Science Council of Canada in the spring of 1980 and is supervised by the Council's committee on Science Education. This paper has three main objectives:

- to establish a documented basis for dealing with the current objectives and general characteristics of science education in Canadian schools;
- to analyze the history of science education in Canada; and
- to promote discussion of possible future orientations for science education.

As the third objective suggests, the Science Council has not yet formed an opinion concerning this reorientation, although it is endeavouring to do so by seeking the opinions of various persons responsible for science education. Council hopes that these opinions, presented in discussion papers that are disseminated as widely as possible, will encourage science educators and others involved to reconsider their objectives and methods. By participating in these deliberations and at the same time by conducting a systematic inquiry into current and past policies and practices, the Science Council hopes to gain an accurate understanding of the state and needs of science education in Canada, and thereby be in a position to formulate useful recommendations.

This document is one of a series of discussion papers that presents various different, if not mutually exclusive, views concerning science edu-

cation. In A Canadian Context for Science Education, James Page highlights the possibilities provided by science courses for making Canadians more aware of scientific matters. Glen Aikenhead proposes, in Science in Social Issues: Implications for Teaching, that the various sciences should be taught in such a way as to show students the relevance of each science and its limitations from the standpoint of social and political issues. In the third paper, An Engineer's View of Science Education, Donald George points out that in the development of science study programs little consideration has been given to the thought processes of engineers, while Hugh Munby's What is Scientific Thinking? examines, from a fresh perspective, how to make students aware of scientific reasoning and develop critical minds. He concludes by showing the importance of training students to be "intellectually independent."

In this discussion paper, Marcel Risi, Marketing Director of the Centre de recherche industrielle du Québec (CRIQ), examines possible relationships between industrial innovation and science education. His approach is systematic and productively stimulating. Looking to the future with a completely open mind, he guides the reader to discover areas which are little known in the world of science education, but whose importance to the future of society is clearly established by the author. The paper concludes with a scenario that suggests a thorough reorganization of science education from a global perspective.

It should be pointed out that the views expressed in this paper are those of the author and do not necessarily represent those of the Science Council or the Council's committee responsible for supervising the Science Education Study. Nevertheless, the author presents a well-supported thesis. Its dissemination will make a contribution to discussion of the orientation of science education in Canada.

James M. Gilmour,
Director of Research,
Science Council of Canada

I INTRODUCTION: A NEW FORM OF DIALOGUE

The attempt to define what should be taught today in order to prepare students for the job market of 1990 or 1995 is really an attempt to define the future. However, no matter how much we may analyze, measure, project and extrapolate, the future remains essentially impenetrable. We must, therefore, begin on a note of modesty. A program about the 1930s was recently broadcast, in which a group of scientists, during that decade, was asked to predict future scientific and technological inventions of significance. They failed to foresee jet propulsion, the development and miniaturization of electronics, or nuclear energy - precisely those developments which were to transform our planet during the next quarter-century. It is clear, therefore, that any attempt to predict, not only the use or appearance of technological innovations, but also the resulting social implications, must take place within the context of futurology.

Attempts to foresee the future by considering contemporary conditions, perceived trends, indicated or intuited developments and analyses of experience to date, projected into the future in a rigorously scientific manner, will ultimately result in no more than a simple extrapolation. However, if particular care is taken in studying the developments, movements and trends that make up our everyday environment, and if to this is added that precious ingredient - imagination - the result will be prediction. The former is no more than a definition of growth, whereas the latter is a thought process that can be used to evaluate development.

We must remain aware that this study of the future may be based on two different perspectives, both of which have their limitations and should therefore be used in tandem. The first, which might be called descriptive and anticipatory, is aimed above all at understanding what conditions will exist in the future and what adjustments will therefore be necessary. The second is normative, and assumes that the future must be influenced in a desirable direction and that immediate steps should be taken to ensure the predicted results. If these two perspectives can be easily distinguished in logical terms, the distinction is far more difficult to make in practice, and studies of the future are usually encumbered by normative forecasts heavily disguised as descriptive. Under the pretext of putting into place today ways of adjusting to the future, we really succeed in putting into place the means that will influence the future.

Both perspectives are, however, linear. As Marshall McLuhan maintains in The Gutenberg Galaxy,[1] printing has had a permanent influence on the Western mind. Human beings have evolved from oral and regional culture towards a linear one (the image for which was provided by the alignment of printed characters in typescript). It could be said that culture runs from left to right and from top to bottom, or that it is transmitted through a long tunnel where only one-way traffic is permitted.

In accordance with McLuhan's famous dictum "the medium is the message,"[2] this paper attempts to discover a new form of nonlinear dialogue, one shaped by the new technology of instantaneous and diversified communication. A television set can receive some thirty channels that provide diversified information; in seconds, the viewer moves from one continent to another, from economics to comedy or war or sex or politics. Information agencies have extended their networks over the entire planet, gathering each particle of information and distributing it. This new dialogue, however, cannot be linear, because it derives from a complex of relationships of convergence and divergence between the "meshes" of the networks, much like a fishing net. It is the crossroads - individuals enter where they wish and depart in the direction they want.

The form of this paper is in keeping with this new dialogue. Readers will not be led by the hand, but by their imaginations and their capabilities - in the end, their desire to break through to new insights will be stimulated. The paper does not explain, it explores; suggests rather than defines; observes rather than debates.

The menu is à la carte. There are three sections: industry, technology and science teaching. If some parts of the paper seem to follow the traditional analytical, linear method, the reader should concentrate on the process of change in each section; the systematic aspect is crucial. Why? To rediscover "natural relationships" between widely differing systems, complex disciplines, unforeseen movements - to call into play intuition, imagination and questioning.

As the purpose of this paper is to provide material for consideration in science teaching, we propose to examine whether, for example, the intellectual current which sustains the process of industrial innovation could not be used in science teaching. One might also analyze whether the process of technological evolution could provide a model for science teaching. The floor is open for debate. The guardians of tradition are eager to slough off their atrophy and examine other methods, other processes and other intellectual relationships.

To stimulate the debate, the sections entitled "Convergence and Divergence" will present potential relationships or starting points for debate, a little like the custom of the "trou normand," in which a glass of spirits is served between courses to prime the appetite. It not only aids digestion, but enlivens the discussion!

It is worth mentioning that the choice of sections simply reflects the author's training and his observations as a university teacher and director of an industrial research centre.

The Macroscole is a scenario, or, as some maintain, a proposal for a holistic approach to science teaching. The Macroscole is the teaching crossroads of all disciplines; it has the potential to shape creative, rather than unified, minds and to provide an education that will be a point of departure rather than an end result.

Whether or not this exploratory paper results in any changes in science teaching, the systematic approach and crossroads dialogue will remain the essential elements of science education in the 1990s.

II INDUSTRIAL CHANGE

In postindustrial society, rapid change has become the norm, making innovation essential to the survival of any industry. Innovation works with other dynamic systems, such as population growth, the growth of markets, the accumulation of technical capital and the increase in human knowledge. The concept of innovation embraces a spectrum of complex and varied factors with imprecise contours. Because of this it is difficult to define precisely, although an attempt to analyze its component elements is possible.

First of all, it is important to avoid expanding the concept of innovation to the point where it becomes confused with that of change. The fact that men today may wear their hair longer is not an innovation, despite claims to the contrary. The process of innovation is normally defined in terms of its result - in other words the creation of a product, the attributes of which create values. A new process or system is thus of value to society if it produces greater convenience, comfort, safety, energy, aesthetic qualities and so on. Inventions such as gunpowder, printing, weaving, the cultivation of the potato and the sugar beet, bleach and the metric system represent undeniable innovations and have two characteristics in common: they were all <u>new</u> and they were all <u>introduced into a specific environment</u>.

Dictionary definitions of "innovation" are too general. More accurate definitions, some of which follow, can be found in the literature on innovation:

- Innovation translates ideas into productive machines and eventually into products;
- Innovation is a social phenomenon in that it modifies existing circumstances and includes an element of risk; it is a complex socioeconomic and technical process;
- Innovation is the process of converting an invention or an idea into a financial success;
- Technological innovation is the process by which an idea or an invention is introduced into the economy.

Without rejecting the above definitions, there is a more comprehensive one: technological innovation is the process by which an idea or an innovation that fills a (potential or existing) need is introduced into the economy so as to generate economic growth, exports and jobs.

At this point, three observations are in order.

First, innovation is poorly presented in science teaching and in scientific books, where the starting point is either the awareness of a fact (such as Newton's apple) or knowledge already acquired (such as Maxwell's laws). Science presents itself as remote from the needs of people, and the satisfaction of those needs is not the object of its endeavours. If scientific knowledge satisfies a need of some kind, at times this may even be regarded as a mistake by the practitioners. The image of science, transmitted by science teaching, is of a researcher in a white coat, ensconced in an ivory tower, cut off from human needs but deriving satisfaction from intellectual pursuits.

Second, this definition does not reflect the various stages from the birth of an idea to an invention that fills a need and is a commercial success. These are generally long, laborious, often frustrating stages, and in most cases extremely expensive. The process is a far cry from the image of the linear experimental method: observation - hypothesis - experimentation - scientific law.

Finally, innovation may evolve equally well from a company's production and marketing functions as from its research and development activities. Real innovation is the sum of at least three functions: creation, production and marketing. A company that is strong in research and development but weak in production and marketing may very well fail in applying a technological innovation. Consequently, when speaking of technological innovation, it is necessary to consider the total design process, along with entrepreneurial, managerial, marketing and financial performance. This constitutes a variable combination of the physical and human sciences which might be termed the science-mix, and is diametrically opposed to what happens in an educational system dominated by a dichotomy between the two groups of sciences.

The Innovation Process

The Function of Information

If it is true that the entrepreneur remains the catalyst who maximizes the probability of success in the innovation process, the most important function is that of information. It sets the process in motion by identifying the need as well as reinforcing the orientation of each succeeding stage.

Before examining the function of information in innovation, we should distinguish between two types of ideas with the potential to lead to industrial innovation. The distinction is accepted by most experts. On the one hand, there are ideas that are stimulated by knowledge of needs or problems (market pull) and, on the other, ideas stimulated by knowledge of a new technology (technology push). These two processes are, in fact, diametric opposites, since in the case of the former the goal is to find a solution to a problem and in the latter, to find applications for which a "solution" is known.

There are two essential questions about the impact of information in the process of industrial innovation. First, what information gives rise to an innovation, or, more precisely, what information leads to the birth

and development of new products by industry? Second, in what way has information contributed to the development of new products?

Three generally accepted statements, which have, in turn, provided the basis for other studies, can be advanced. The first two are more applicable to the phase in which ideas are generated, while the third, applies more to the problem-solving phase.

Statement 1 - The Birth of Ideas

Ideas oriented towards new products result more frequently from the identification of a need or problem than from the identification of a technique or a means.

Statement 2 - The Age of Applied Technology

The basic technology applied in innovations stimulated by technical possibilities is more advanced than that used in innovations stimulated by a need.

Statement 3 - The Hierarchical Sequence in the Search for Information

The search for information normally evolves from local and easily accessible sources (publications and reports), to secondary sources (communication with others) and finally to primary sources (analysis and experimentation). The first two are more significant in the development of innovations generated by technology than in the case of those based on need.

These statements are founded on data culled from a variety of reports. They reveal the need for the creation of a crossroads between upstream and downstream information and innovation, a convergence that should result in information.

Table 1 presents the chronological path of the major stages in the innovation of a process, product or service. Stages 2, 3, 4, and 6 are usually carried out by scientists, engineers and researchers, although it is worth noting that their work will never bear fruit for private industry or the public if the other stages are neglected. However, experts in the "human sciences" should be involved in all stages in order to evaluate the

costs, both those already assumed and those anticipated, to ensure the most effective evaluation of the ultimate impact of the investment, to modify the objectives in terms of customer need and to create the necessary capital.

Table 1 - The Major Stages of Innovation

Variation of time	1. Identification of customer need. 2. Generation of ideas or of an invention. 3. Review of knowledge and know-how in science, technology, economics and marketing etc. This is a feasibility study. 4. Development - Identification and solution of problems - Test and market study
Increase in cost	5. Establishment of risk capital.
Evolution of technology and of the socioeconomic environment	6. Change due to start-up - Design, engineering and tooling - Factory start-up and market launch 7. Marketing and sale of the new product, process or service. 8. Distribution to users. 9. Satisfaction of customer need and attainment of the corporation's objectives.

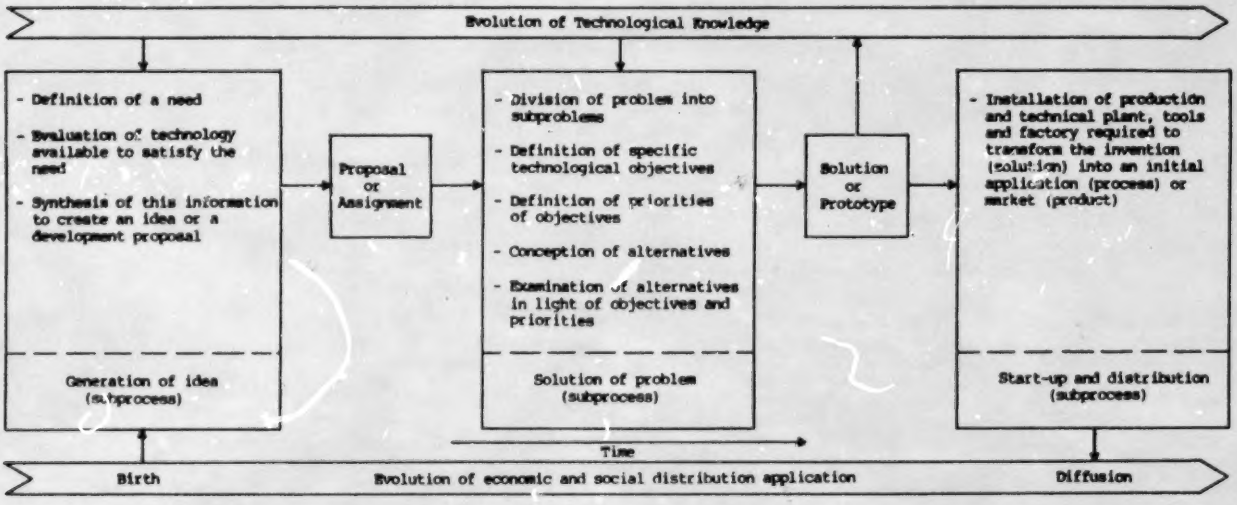
How can the stages described above be organized into a system? Several models have been proposed and analyzed, including the classic one - the staircase model - developed by Lionel Cox[3] of MacMillan Bloedel and submitted to the Lamontagne Commission. This model, which involves basic research, applied research, implementation, development, marketing,

business growth, job creation and profit, represents the same linear process that characterizes innovation in the relevant literature.

The Gruber and Marquis Model

The model with the most realistic parameters was proposed and developed by Gruber and Marquis[4] of the Massachusetts Institute of Technology (MIT). On the basis of industrial experience by Myers, Marquis and Utterback of MIT, it was subsequently refined and expanded upon.

Table II - The Innovation Process*


Evolution of Technological Knowledge
- Definition of a need
- Evaluation of technology available to satisfy the need
- Synthesis of this information to create an idea or a development proposal
Generation of idea (subprocess)
Proposal or Assignment
- Division of problem into subproblems
- Definition of specific technological objectives
- Definition of priorities of objectives
- Conception of alternatives
- Examination of alternatives in light of objectives and priorities
Solution of problem (subprocess)
Solution or Prototype
- Installation of production and technical plant, tools and factory required to transform the invention (solution) into an initial application (process) or market (product)
Start-up and distribution (subprocess)
Time
Birth
Evolution of economic and social distribution application
Diffusion

*Source: Gruber and Marquis, Factors in the Transfer of Technology, MIT Press, Cambridge, Mass., 1969.

In this model, the process of technological innovation is presented in the context of the real world with its political, cultural and social elements. The state of technological knowledge, as an integral part of scientific literature, seminars, modern techniques, patents, and catalogues of all sorts of elements, is one important aspect of this environment. The model suggests that technological knowledge is continually evolving in time, as indicated by the horizontal arrow at the top of the table. The economic and social aspects of the use of products, processes and services

is also an important factor, one defined by other companies in the same industrial sector, by competition, and by present and future users.

It is astonishing that this model also reveals the necessity of a good science-mix. This is the opposite situation to that found in most teaching methods, where there is a reluctance to create an explosive mix of creativity, not only between various disciplines, but even within the same discipline. As a result, physics is always taught by separating such aspects of the subject as, for example, statics, cinematics, dynamics, optics and electricity.

The Practical Implications

When the statements on the use of information are related to the model of the innovation process, the practical implications are interesting. These could be compared to certain so-called well-founded opinions that are very popular in educational circles.

In relation to the phases of the innovation process, we can conclude that:

- Information usually originates from outside the company during the generation of ideas phase (Statement 1) and the use of internal sources predominates during the problem-solving phase (Statement 3);
- Verbal communication is the most important source of communication in both phases (Statements 1 and 3); and
- The search for information is more highly structured during the second phase than during the first (Statement 3).

In relation to the sources of information, we can conclude that:

- The generation of a new idea is usually stimulated by the identification of a need or problem, followed by the identification of the technical resources that could satisfy the need or solve the problem (Statement 1); and

- In the minority of cases where ideas are stimulated by technology, the technology is recent and most of the information used originates in publications and technical consultations from outside the company (Statement 2).

In relation to the organization of this model, two critical factors should be taken into account:

- the integration of commercial and economic information with technical information (Statement 1); and
- analysis and communication of needs and problems (Statement 2).

Would it be a useful exercise to analyze a number of textbooks, which are basic sources of information, to see whether they meet any of the requirements expressed here? Is the answer inherent in the question, or does the question disturb intellectual complacency and the comforting round of daily repetition?

The Function of the Entrepreneur

In Gruber and Marquis' model, innovation results from a satisfactory relationship among four functions: information, research, production and distribution. The relationship is affected by the evolution of technology and the socioeconomic environment. The point at which these four functions intersect is the domain of the entrepreneur, the "venture manager" and the innovator.

If business people understand their role properly, they will stimulate creative behaviour on the part of the entire innovation team. According to Cox,[5] technological entrepreneurs or venture managers have the reputation among company management of getting things done. They (the entrepreneurs) are well aware of how an idea is born, evolves, is financed, marketed and managed in order to create a new and profitable undertaking. They take risks and dare to be different. They are impatient with delay, very sure of their own abilities and respectfully sceptical of what is already known. Their immediate superiors often regard them as hard to handle,

excessively frank and sometimes abrasive; but for their subordinates, they are sensitive to and understand what motivates those with whom they come into contact. The entrepreneur is a catalyst who succeeds in transposing science and technology into the marketplace by his or her enthusiasm, courage and persuasive tenacity.

It is quite clear from this description of entrepreneurs that they are not only key figures in any innovation process, but also are generally quite different from researchers. They can, nevertheless, be either stimulated or crushed by certain aspects of their environment. Entrepreneurs must work where there is decentralization and delegation of responsibility because excessively rigid policies or onerous supervision can create a hothouse atmosphere that stifles risk taking. They are also in mortal danger from the finance-accounting syndrome, endless meetings, vague communication and bureaucracy. This type of management creates good managers but not entrepreneurs. In other words, <u>good management and entrepreneurship are not necessarily synonymous</u>.

Convergence and Divergence

- *Might the entrepreneurial model be applied to our educational system?*
- *What educational activities could be created to simulate the behaviour of the entrepreneur?*
- *How can an entrepreneurial profile be developed in a student while retaining his or her acceptability to other students?*
- *Might the innovation process, either in its entirety or in some of its aspects, serve as a model for teaching a science-mix, given an integrated approach to the teaching of the physical and human sciences?*
- *Can science teaching be "market pull," i.e., oriented towards responding to questions or needs, or can it only be "technology push," presented as a solution to future problems?*
- *If a teaching model of the science-mix type is accepted, how can chemistry and marketing be taught in the same course?*
- *Because innovation generally makes use of recent technology, why not teach only "new technology"? What would be the point of teaching Bohr's model of the atom?*
- *It has been established that the structure of thought transposed to textbooks provides a framework for and forms the thought processes that the student will subsequently use. However, it has also been established that verbal communication is more important than written in the stimulation of creativity. So why write textbooks? Should not teaching ignore the written word?*
- *What would be the practical implications for science teaching of the three hypotheses about the function of information?*

The Origin of Inventions

Innovation is a process, managed by an entrepreneur, who uses information as raw material to be processed. If these were the only conditions necessary to create an innovation, it would be a simple matter to reproduce them "in vitro." But there is a snag. People are not machines with predetermined characteristics for the purpose of production. They are infinitely diverse individuals in terms of both their abilities and their limitations. Therefore, the entire company is involved in the process of innovation.

Studies, in general, have shown that innovative companies have special characteristics. These relate to four aspects of their organizational structure and resources.

Decentralization of Authority

The first characteristic, which lies buried under a substantial number of prejudices, myths and contradictions, is the decentralization of authority. Many companies believe that by decentralizing their operations they have achieved decentralization of authority. Decentralization of authority, however, involves a great deal more than the mere decentralization of factories, supervision and responsibilities. Authority is the freedom and ability to choose. Authority is truly decentralized when individuals can choose for themselves the appropriate methods and techniques to achieve an objective, and can even choose their own objectives within the company's overall development plan.

Capacity to Absorb Mistakes

A corporation must recognize the inherent risks in innovation and the high possibility of failure. Financially it must be able to absorb errors that result from creativity. Otherwise it will survive only if there are no mistakes in the short term and will limit the scope of its exploration to immediate problems.

Flexible Communications Network

A number of catalysts stimulate the innovation process. The most important is communication, for the creators must be in constant contact with even the most insignificant aspects of the organization and its environment.

James R. Bright[6] has carried out a study in which he analyzes a series of inventions that came, not from the industries in which they would normally have been expected to originate, but from unexpected sources. For example, nylon, a synthetic fibre, was created by DuPont, a chemical company, and not by the textile industry. Because of its closed system, the textile industry would not have welcomed the innovation, regarding it as outside its own field and therefore constituting a potential danger. DuPont, however, built factories for the new fibre.

The study also analyzes a list of 18 important innovations launched by DuPont between 1920 and 1945. Only five of these had no connection with any outside source, while the others originated with the purchase of patents which were subsequently improved upon, either because the exploitation of risks had revealed unexpected uses for the product, or from contacts with consultants, suppliers or customers.

There is no serious, tenable way to justify a rigid or restricted communications network. Most innovations are dependent on flexible communications - an essential stimulus for creative minds.

Management of Human Resources

In addition to these three characteristics related to organization, any company that wishes to be innovative must also make, as one of its prime concerns, policies concerning the management of human resources.

Obviously a company must hire creative individuals. Because creators are often unconventional and a little strange, they work differently than others. The company must encourage their integration by creating a place for them within the organizational structure.

Industry is on the threshold of a dramatic change in human resource management. Managers will be required to mix technology and human values judiciously. Increased productivity is the revolutionary slogan that will sweep away companies that fail to adapt. The road may be long.

In the United States, as in Canada, productivity growth in the economy has, in general, been poor in recent years. While technological progress may help to improve productivity in some sectors, it must be supported by people with the correct skills. For example, many experts anticipate that by the year 2000 many factories will be controlled by computers. A number of social as well as economic factors, which the experts claim are readily apparent today, are encouraging this trend. As far as economics is concerned, low productivity results from the substantial waiting period between the various operations carried out at each stage of the assembly line. The real time during which a machine is in use could therefore be increased. Social incentives for automation include: growing resistance among workers to a work environment in which they are exposed to health hazards; employers' awareness of the need for job satisfaction; and governments' increasingly widespread concern over job safety. To these factors must be added the fact that the technology required for this high degree of automation now seems feasible, thanks to the rapid upsurge in the capacities of digital computers, the use of integrated circuit systems in manufacturing, grouped technology and modular manufacturing.

A complete rethinking of the management of people is needed. But how can people, educated in a linear, binary, segmented or disembodied system, develop integrated thought processes and judgement that take a variety of factors into account? Should we consider a return to "classical education," a suggestion implied in some American studies that indicate that the best managers are generalists?

Convergence and Divergence

- *Could teachers be given sufficient autonomy to propose changes in courses and the relative importance of each course?*
- *How can students be helped to discover their abilities and limitations?*
- *Is the present educational system adequate in light of the need for integrated knowledge in a world dominated by the goal of high productivity? Should the physical sciences be eliminated in favour of the "human sciences"?*

A Typology of Innovation

Innovation is both a process and its result; it is also the catalytic effect of the entrepreneur, the transformation of the raw material - information - and the adjustment of organizational parameters to encourage the synergy of human relations.

The above immediately reveals a diversity that is hard to identify without the broad outline of a typology to specify the content of innovation and attempt to classify its main categories. The typology we propose deals with the nature of innovations, and thus with the products of innovation.

It should be mentioned that it would have been possible to classify innovations either as a function of the degree of innovation or as a function of their process. Three characteristics are generally recognized in relation to the degree of innovation: first, radical or absolute innovations (such as the transistor); second, relative innovations (such as plastic extrusion techniques in relation to metal extrusion techniques); and finally, initial imitation innovations (such as the manufacture in Québec of beer spigots copied from a new French product). Moreover, if we

concentrate on the process of innovation rather than on the product, we must also consider the factor of anticipation that distinguishes pro-active innovation, which shows a company has anticipated the developments in its environment, from reactive innovation, which consists of finding a new solution to a problem that has become awkward.

Unfortunately, these distinctions give the impression that contemporary education, which encourages the acquisition of traditional knowledge, encourages innovation. This is far from being the case. We must develop in the student the mindset of the innovator who must respond to a wide variety of information; this becomes clear if we examine the nature of innovations.

Let us therefore look at a more practical classification based on the nature of innovations. The various categories should not be regarded as hermetic, for most innovations result from a combination of the elements within each category. For the sake of convenience, however, the major distinguishing features of the innovative product have been singled out.

First, is the major group - technological innovations - which consists of the following seven categories:

New substances or raw products:

stainless steel, DDT, formica, penicillin, polyurethane, nylon, the semiconductor;

New components, elements or subsystems:

the transistor, printed circuit, velcro, the safety windshield, radial tire;

New finished products, from the simplest to the most complex, based on one or two simple principles:

the ballpoint pen, contact lenses, the interchangeable blade razor, the electric toothbrush, the birth-control pill;

New complex systems, which, with varying degrees of originality, combine more or less new elements in a set of scientific principles:

colour television, the air-cushion train, automated computer-controlled warehouses, optical readers attached to cash registers;

New modifications, which make the product easier to use and transport, or increase its convenience:

shoe-polish in a tube, disposable toothbrush, frozen puff pastry, instant coffee, aerosol depilatory, the lubricated condom;

New ingredients (raw materials, energy sources), the use of which make it possible to produce the same or a similar product with a different output:

geothermal energy, wind-generated electricity, scrap metal, rigid plastic as a substitute for aluminum, dielectric plastics;

New processes using new equipment:

oxygen steel-making, floated glass, laser cutting of fabric, nonwoven fabric, radiography of wet fabric through ultrasonic transparence.

Next is the large group of commercial innovations, where the innovative aspect is to be found essentially in the "downstream" operations, in other words, the marketing aspects. This major group has five categories:

New format for a product:

the pocketbook, original packaging design which changes the perception of the product;

New distribution methods for a product:

the sale of plastic articles at women's parties (Tupperware);

New applications of an existing product:

the birth-control pill, drive-in movies;

New methods of sales promotion, which involve the idea of an original public relations or advertising campaign:

the most striking example of this was unquestionably the advertising campaign that said only: "There will be no advertising";

New commercial systems:

the "cash and carry" system, the supermarket, the credit card, leasing of industrial equipment.

The third major group covers innovations in the organizational structure of the company, in its procedures and its development patterns. These are organizational innovations:

- the PPBS known by the expression "rationalization of budgetary options";
- the matrix organizational structure;
- automatic debiting of a budget;
- negotiable room rates for hotels;
- manufacture under licence.

Finally, there are public sector institutional innovations that generally result in the establishment of new standards and thus of new systems designed to further socioeconomic progress. Some examples are:

- the elimination of the sales tax on consumer products;
- tax deductions for R&D expenditures;
- legislation concerning cooperatives.

This typology was developed in the course of a study conducted jointly by the Délégation générale de la recherche scientifique et technique/ Scientific and Technical Research Board (DGRST), the Institut français de gestion/French Management Institute and the Bertin Corporation. From the typology, the following conclusion can be drawn: the process of industrial innovation reaches far beyond the so-called physical sciences to draw, in most cases, upon knowledge and experience related to the human and administrative sciences. Consequently, the information sought is just as likely to be available at the basic level of information in catalogues and even in the yellow pages of the telephone book.

Convergence and Divergence

- *Would it be possible to develop a typology of courses based on their possible impact on various forms of innovation?*

- *Is science teaching the only branch of education leading to industrial innovation? What relationship should there be between science teaching and the teaching of other disciplines - in particular, history, geography and French?*

- *In that the analysis of the nature of innovations reveals the active interdependence of the physical and human sciences, would it be possible or beneficial to develop new courses or variants of courses that would enable the student to develop an innovator's profile rather than intellectual knowledge and abilities? After two decades of decline, is a "classical education" really so poorly adapted to society's needs?*

III THE TECHNOLOGY OF THE 1990s

President Kennedy's claim that the United States would put "a man on the moon by 1970" was greeted with extraordinary enthusiasm and stimulated society with a vigour unparalleled in the intervening decade. It is doubtless fanciful to try and anticipate what cause or topics might potentially generate new motivations and new ideals in the field of science and technology in the approaching decades. They will, however, probably be related to the quality of life and to the major problems of the world, to the extent that these, on the basis of present circumstances, can be speculated on. Some observers are beginning to alert public opinion to the dramatic increase in the importance of such questions as population, food supply, nonrenewable raw materials, the environment and energy. The resources of science should be enlisted to help manage these issues.

Training young people who will have to confront a working environment evolving so rapidly that the knowledge they have acquired is frequently obsolete or no longer required is one of the challenges facing education. Education today must anticipate an often unforeseeable future. Let's attempt to imagine the future, at least as far as technology and its implications for daily life are concerned.

Energy

The new energy situation has begun to influence the behaviour of companies and, given the gradual exhaustion of certain resources and the substitution of new forms of energy, there is no doubt whatsoever that it will continue to do so over the next few years. Those industries quick to turn towards

more abundant sources or sources with a greater security of supply will rapidly gain a competitive edge.

All the forecasts agree on one point: the cost of energy will increase at least as fast as the cost of other commodities. In the immediate future, conservation has the greatest potential for regulating the looming energy crisis, since new sources of energy will not be available until 1990 at the earliest, even assuming that research is undertaken immediately.

Products that use oil as an ingredient rather than as a source of fuel will be most directly affected by the crisis. Consequently, there will be opportunities for innovation in companies manufacturing products from oil substitutes. There will be similar interesting prospects in the primary energy sector, and in the design of equipment for the conservation or more efficient use of energy in the manufacture of goods. In future, it will be necessary to discover how to ensure greater security of supply in areas such as the transportation and storage of energy and in the use of a mix of energy sources.

Generally speaking, energy-related research will remain very active, especially since, given the present state of technology, it is impossible to make a definitive choice among alternative energy sources. Moreover, the need to accumulate research results in all fields will be felt for many years. We can anticipate that this area will continue to account for approximately one-third of all civilian research and development expenditures.

Convergence and Divergence

- *What relationship can be observed between the energy situation and the teaching of biology?*

The Environment

Independent of, but concurrent with the energy crisis, is the state of the physical environment, which is gradually deteriorating as a result of increasing economic activity. For example, the general degradation of the natural environment is a consequence of the chemical products and pollution produced by industry. The most recent manifestation of the widespread extent of pollution, hitherto assumed to be an urban phenomenon, is acid rain, which destroys life in lakes and on agricultural land. Pollution is now everywhere. The energy crisis will exacerbate the process, either by encouraging governments to lower standards and regulations to permit the use of those energy sources considered harmful to the environment (such as coal and the production of energy from nuclear power stations), or by industry's recourse to means of production which will further pollute the environment. Despite everything, environmental regulation and monitoring will continue and industry should continue to adapt to the regulations.

Giant steps have been made during the past decade in the area of environmental quality control and, in general, the public has supported them. Environmental protection movements and protest groups are and have been active. At the same time, however, economic considerations have exercised a powerful restraining influence on environmental quality control. It is therefore expected that a certain level of pollution will necessarily have to be accepted. Particular standards will be abandoned if their cost is prohibitive, even though they would result in complete protection in terms of health. However, there is also greater concern with the accuracy of such conventional evaluations. Questions are being asked, for example, about the best way to judge the benefits to the national economy of industries and services based on the protection of the environment. Pollution may well create a new and profitable industry.

Convergence and Divergence

- *What are the elements that pollute the educational environment? What criteria can be used to establish a "tolerance level"?*

Biotechnology

The stuff of dreams . . .

The biotechnical revolution will have a radical impact on agricultural methods and the food industry. The era of bacteria is upon us, providing human beings with new allies or perhaps new slaves - it all depends on waste.

Biotechnology is defined as "the use of a biological process either within microbic organisms, or in vegetable or animal cells or their components, in order to produce goods and services" (Rapport Brossard).[7] It is the use of the infinitely small to meet our infinitely large needs.

Biotechnology employs extremely complex techniques:

Genetic engineering enables a microorganism to acquire new genetic properties and thus the ability to produce a new substance, to serve another purpose, or to alter a particular substrate;

Enzymes and enzymatic systems find a new application in health care; in the past they were used primarily in the food and detergent industries;

Cellular fusion provides the opportunity to fuse two cells to produce a hybrid. There are a multitude of potential applications for this process, in agriculture, forestry and medicine;

Vegetable cell culture enables vegetable cells to be cultivated "in vitro," producing agents used in the manufacture of medicines;

Process and systems engineering revolves around the development, regulation and control of new processes in bioengineering.

The term biotechnology is a new leitmotiv in both scientific publications and in economic and financial periodicals. Risk capital is starting to flow slowly away from electronics and microelectronics into the direction of biotechnology. Probably the market will reach maturity in one or two decades. Here again, the risk of missing the boat is high if education remains oriented towards the past and is transmitted within a compartmentalized system. Managers in the field of biotechnology will need the ability to judge parameters derived from both the exact and the human sciences within the overall framework of social morality. Any society bears the responsibility for the monsters it creates, whether they be nuclear or microbic.

Convergence and Divergence

- *What sort of eco-ethic must be developed in students so that biotechnology will be used to improve the quality of human life?*
- *Should ecology be "taught"? Can ecology be classified as a human or a physical science?*

The Redeployment of Technology

The Lamontagne Report's[8] cry of alarm, "Innovate or perish" is still appropriate. However, innovation is not only technical - it involves other kinds of knowledge and human activity. In consequence, more attention is being paid to improving research management through detailed analysis of the impact and rigorous evaluation of the cost of the resources employed. Researchers themselves are increasingly required to question the finality and the possible consequences of their work. This they are doing with great intellectual honesty and, admittedly, because of the pressure of vigilant public opinion, they are also sometimes subjecting themselves to regulation. One recent striking illustration is the restrictions placed on

genetic manipulation. The question is whether this rather fragile balance between researchers and the public can be maintained if substantial industrial interests are involved. In the eyes of society, scientific progress has become subject, if not to actual control, at least to a permanent scrutiny that will inevitably affect its development. At present, this trend is apparent in a very general way in both government and private sector R&D programs.

This brief outline of the path that technology will have to take in finding solutions to energy, environmental and biotechnological problems is indicative of a new situation: the psychological revolution, the initial elements of which are visible in both researchers and the public.

In the early 1960s, Teilhard de Chardin, in his work The Phenomenon of Man,[9] was the first visionary to call this revolution a successor to the agricultural revolution of ten thousand years ago and the industrial revolution of less than three hundred years ago. He saw this psychological revolution as the outcome of our philosophical and spiritual evolution. Recently, Alvin Toffler, in The Third Wave,[10] after examining such diverse fields as the economy, energy, psychology and communications, discerned the first signs of a profound change in human mentality.

For Toffler, throughout the second wave set off by the industrial revolution, work was systematized and compartmentalized. In accordance with the Judeo-Christian concept that work was a painful duty rewarded in the hereafter, the ideal employee was docile, punctual and tolerant of routine. The educational system encouraged this behaviour by rewarding the studious and budding geniuses; the university and state supported it by distributing medals with the inscription bene merenti (to the well-deserving) to their dutiful employees; and industry rewarded it by presenting a commemorative plaque to employees for 25 years of loyal service.

Certain features of the psychological revolution should have a direct influence on work and teaching methods. One influence involves the

employee who demands a more varied workload and greater responsibilities. This is the reason for the popularity of part-time work and flexible hours, both of which remove the unconditional acceptance of uniform behaviour. This rejection of uniformity should also give rise to new structures in school, although little attention has been paid to this aspect of education. Perhaps teachers should be the first to discard the mask of stereotyped behaviour.

Given the growing complexity of technology, however, schools have the responsibility of training people to be capable of understanding the way in which their specific tasks fit into the overall scheme of things and also to adapt more rapidly to change. One response to this challenge is the cooperative teaching system adopted by some universities. Schools should follow this example. Here again, research is needed.

The models of authority of today will disappear. At present, each employee is responsible to a single superior within a structured hierarchy. A number of progressive organizations have already introduced a far more complex hierarchy, in which work methods are based on the principle that ideas are produced from a clash of minds and where a great deal of importance is placed on divergence of opinion. In consequence, employees and students who are intellectually independent, aware of their social responsibilities and demanding in their attitude to authority will become indispensible to the organization or school in which they are today regarded as disturbing influences.

Will the process of innovation always occur in response to a need? Is this a truly positive factor? Is this relevant to what is really important to the employee, the employer and the consumer? Is the cost always justified, or is the price of a product artificially inflated on the pretext of innovation and the desire to increase profitability? Does this type of innovation not result in a more difficult and more expensive management of goods, since repairs become more complicated and demanding in terms of manpower? Have the consequences for health and the environment not been

pushed into the background on the pretext of innovation? If all these questions are valid, it is because there are misguided innovations. Innovation has hitherto been concerned particularly with the need for profitability and has often neglected more basic social needs. From this point of view, it is but a short step to banning innovations. This is not a viable option, as innovations have already made, by providing a more comfortable life, a substantial contribution to the conditions under which we live and work. There can, therefore, be no question of simply limiting the development of innovations a priori. However, development should be placed under surveillance, put on parole so to speak, while attempts are made to give it direction and place it in the proper framework.

Perhaps this constitutes a new goal for education: train young people so they will be able to find compromise solutions between diverse and complex elements. This would require the adoption of educational methods which are far more synthetic than analytical.

Convergence and Divergence

- *Is the psychological revolution an illusion?*

IV THE TEACHING OF SCIENCE

Teaching today is linear - the ideas, developments and subject matter studied are all presented in a sequential manner.

This is the educational tunnel. In order to come out at one end, you must enter at the other. Worse, it is a one-way tunnel. "Sir, of what use is what you are teaching?" asks the student. "You are here to learn and it will be of use to you later," is the teacher's motivating answer!

The changes individuals must face throughout life, either passively or as initiators, can only be the result of a rational process. Adapting to these transformations requires a degree of creativity which itself results from knowledge, imagination and the environment. Here lies the essential function of education, with its direct impact on the scale and orientation of knowledge, and on the use and control of the imagination - to help cultivate the capacities of individuals so they will then be able to alter their environment.

Education in a rapidly changing environment should provide individuals, not with information on the way things are so that they can adapt to them, but rather on what they are so they can adapt their environment to themselves. Bernard Shaw wrote, in what was probably a prophetic vision: "The reasonable man adapts to the world. The unreasonable man tries to adapt the world to himself. As a result, progress depends on the unreasonable man." Paul Valéry phrased it similarly: "In the profession of philosophy, it is essential not to understand."

Just as our earlier exploration of industrial change and technological development singled out only those elements that affect society, we shall in this section attempt to consider education in the same way - as a dynamic system, a process that transforms input into output.

The Process of Creativity

If there is any truth to one of the axioms of the Lamontagne Report,[11] "Innovate or perish," Canadians are destined to perish! If the generally accepted criterion for measuring creativity is applied, Canada lags far behind other industrialized countries in this area.

One of the indicators for measuring the creativity of companies is the number of patents applied for each year. The figures obtained, however, demonstrate the degree of industrialization of a country and not its creativity, which should be related to the company. A more sophisticated indicator, calculating the number of patents by year and by engineer or technician employed in research, has emerged. Table III uses the United Nations (UN) and DGRST (Délégation générale à la recherche scientifique et technique). The 1971 data for Canada were provided by federal agencies.

Table III - Measurement of the Creativity of Companies

Country	Number of applications	Number of researchers	Number of patents by year and by researcher
Japan	78 500	396 000	0.19
Germany	33 000	270 000	0.12
Austria	2 600	23 000	0.11
France	14 000	139 000	0.10
United States	76 000	752 000	0.10
Canada	1 850	52 600	0.03

Despite its imperfections, this indicator shows that France lags 20 per cent behind Germany and 47 per cent behind Japan, a country known for its industrial ingenuity. The low figure for the United States reflects the importance of basic research in that country. Canada's miserable performance is due to a variety of factors, including the cost of development, foreign ownership of industry and the shortage of grant programs in comparison with other countries. Perhaps most important is the lack of teaching and work methods designed to stimulate and channel the creativity of individuals, regardless of age, sex or job.

The Profile of the Creative Individual

Studies have revealed certain characteristics of creative individuals; these have provided the basis on which many methods for stimulating creativity have been developed and successfully applied. In view of the importance of the subject and its implications for teaching methods, we felt it merited lengthier treatment. Appendix I contains additional details about both the characteristics of and teaching methods for creative people. Teachers would do well to become acquainted with them and learn from them, even though this would doubtless disturb the existing system.

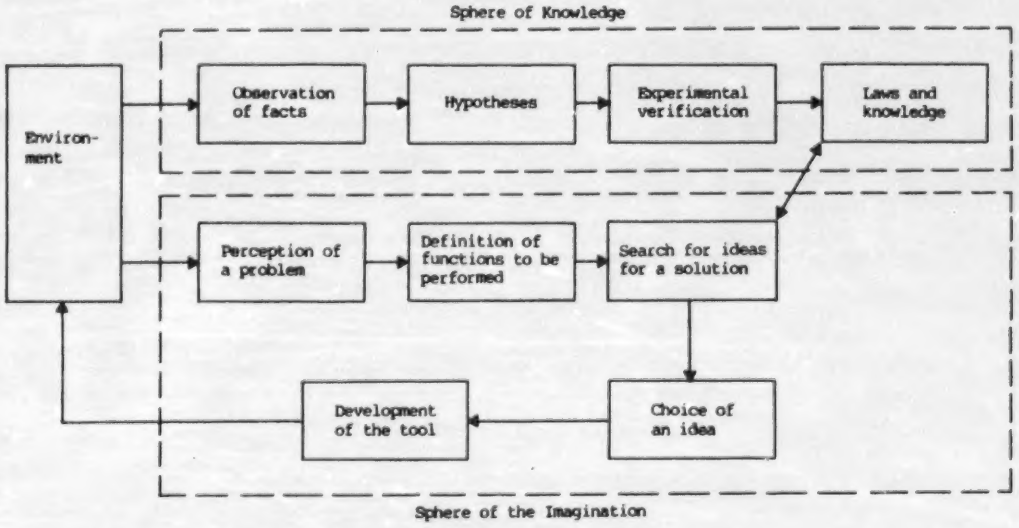
In sum, creative people possess great conceptual flexibility and prefer complexity. They are sensitive, but have their thoughts well under control. They are fundamentally independent and profoundly motivated. Communication is for them an essential condition of existence.

The Two Routes

We must understand the process of creativity in order to develop this profile of the creative individual. The process has been described frequently, in particular in Québec Science Education: Which Directions? (Les sciences au Québec: Quelle éducation?). In this work, the description of the creative process is based on a concept sufficiently broad that anyone can find his or her own place in it: "the environment of the individual" or "the world in which individuals live their daily lives." Two creative methods can emerge from such an analysis of the environment. Table IV

below shows a schematic presentation of the connection between the various elements of the two processes.

Table IV - The Elements of Creativity*



*Source: Québec Science Education: Which Directions? Science Council of Canada, March 1982.

Teaching generally uses the experimental method, as dictated by students' textbooks. Nevertheless, there is a fundamental error here: the process normally begins with "the spirit of curiosity" which observes a fact and asks a question. The classic example is Newton, who saw an apple fall and asked, "Why did it fall?" The student does not experience this curiosity, but is obliged instead to go through the experimental process, inevitably exclaiming at the end: "What use are all these demonstrations and all these laws?"

Then there is the heuristic method, an attempt to make students discover for themselves what the system wishes to teach and transmit. This method stimulates the imagination to arrive at "an understanding of what is"; it is used in some textbooks, but undergoes a "neurological mutation" when it enters the brain of many teachers and emerges in the form of the experimental method.

Both methods are limited to their common goal - the acquisition of knowledge - without teaching students why it should be acquired, except that "it will be useful one day."

Mission accomplished. The pitcher is full, but of what use is it? None whatsoever - for neither curiosity nor imagination have been stimulated. They have remained dormant throughout the entire process of acquiring knowledge.

Convergence and Divergence

- *How can the two creative processes be compared to the process of teaching science?*
- *What is the importance of the contribution of the physical and human sciences in each process?*

The Development and Influence of the Computer

Computers can process information, store it, and process it in real time. There has been an astounding increase in processing power, equivalent to the power of nine, from seconds to nanoseconds. Storage capacity (the amount of data recorded) has moved from magnetic cylinders to solid state systems that provide instantaneous access to several million characters. The introduction of magnetic media, from tape to discs, is without a doubt

the most important storage development. There is virtually no limit to the amount of information that can be manipulated in an interactive mode in a computer system.

The great disappointment of using computer technology lies in the inability to establish a real link between the user and the machine; it is still impossible to communicate easily with a computer-based information system. Most of the systems designed with this purpose in mind are still rudimentary and the input must be organized within a rigid structure. In-depth knowledge of the system, in order to guarantee its effectiveness, is also necessary. Recent developments, however, such as "artificial intelligence," open new horizons.

The use of minicomputers and microcomputers will soon be widespread. In five years' time, distributed processing, using one or other of the following structures, will be the rule. In the first, individuals will use small computers that are not interconnected and have no centralized control. The second will be based on a system of small computers with a form of centralized control. The advantage here will come from the use of mini or microcomputers as intelligent peripheral elements in a vast system. In any attempt to forecast the future, minicomputers and microcomputers are essential elements, as are computer networks and new uses for data bases.

The interface between the machine and the user is the second important element that will have a profound impact on information systems. This change will follow the evolutionary pattern of what is now called interface psychology.

The majority of users in the future will no longer be specialists - analysts, librarians, information science experts and so on. All the operations required of the operator at present are mental activities which are not "natural" for storekeepers, doctors, accountants, managers or civil servants. There is an urgent need to design "dialogues" for these future

operators. These dialogues should be interesting and intelligent, as this is the only way to achieve wider use of available knowledge and the ability to develop a distributed processing system. This will be the most important development of the next few years.

In the future, intelligent peripheral elements will be used as the interface between "man and machine" and as the creators of a dialogue between humans and machines. As a solution, it is acceptable both in terms of user psychology and cost; it will also produce a renaissance in education and profoundly change teaching methods. Unless they wish to accept a time-lag in the quality of the knowledge they pass on, schools should encourage computer-assisted teaching. However, it will be necessary to change attitudes based on preconceived notions, for it is not possible to transplant the content of current courses onto the computer. Moreover, it would be dangerous to regard the computer as a substitute for the teacher. The computer does not transmit knowledge. The computer itself should be studied in a way that is conducive to analysis and to knowledge of the learning process, because the goal of all teaching should be the learning process itself rather than the knowledge acquired. The objective should be: learn to learn. Ultimately, the computer should be used to simulate real-life situations by defining needs and to search for new methods for problem-solving. There is no single solution to a simulated problem; there are only more or less effective solutions.

Convergence and Divergence

- *If the information and the knowledge is available on computer, what is left to teach?*
- *Which subjects can be taught by computer?*

V ONE SCENARIO: THE MACROSCOLE

In this paper we have presented three systems for studying the process of development and identifying certain determining factors, without drawing the necessarily logical, proven and linear connections between the whole and its parts or between the various parts. The reader is free to imagine whatever connections he or she wishes.

The purpose of this approach is to identify the salient characteristics of the industrial world, technological development and science teaching by examining the tentative gropings of social innovations, with their successes and failures, in order to arrive at a new project and a new scale of values.

A conclusion would be against the spirit of the crossroads dialogue. This type of dialogue does not lead to conclusions, but to possibilities - it defines an infinite variety of probable futures rather than a single future. The dialogue produces one of many scenarios, located somewhere between the probable and the possible, which are separated by political will, crisis, the psychological revolution and so on.

In our scenario, people will emphasize human relationships on the one hand and, on the other, the relationship between the individual and his or her natural environment: this is the ecosociety scenario.

The Ecosociety

In the ecosociety, the course of industry and industrial innovation will be set by bioengineering and ecoengineering; the mastery and imitation of microorganisms to produce food and chemical products will lead to less pollution, less energy-intensive and more easily decentralized processes of production.

While retaining the freedom essential to the stimulation of its ability to innovate and adapt to competition, a company will be subject to strict monitoring by consumer and user groups. Together with government, these groups will determine industry's ultimate goals.

The economy will be based on the service industry. It will have to abandon principles based on material goods in favour of an exchange of services; and substitute the fermentation of ideas for the fermentation of sales and business deals. Advanced communications will make it possible for minisocieties to communicate, and decentralized data processing will stimulate intellectual activity.

The industry of the future will be in balance, after a revolution in habits and modes of thought, with the goals of equality and justice in progress.

Ecotechnology

Biology will be the source of technology in the ecosociety. Biotechnology will determine the relationship between natural cycles and the metabolism of the "social organism." The reality of disconcerting, dangerous genetic manipulations, synthetic genes and modifications of the electronics of the brain will necessitate the creation of a new balance between science and politics and between science and morality.

Ecotechnology will encourage the recycling of energy and raw materials. It will result in more lasting products, and revitalize the crafts industry. Ecotechnology's two goals will be to meet human needs more effectively and to make better use of nature.

Ecoeducation

In its pursuit of balance, the ecosociety will provide ongoing education for everyone, regardless of age, so that citizens can acquire knowledge at their own speed. Acquiring knowledge will be based primarily on the games method, which defines a real situation and concrete needs and requires the player to suggest a possible solution. The computer will be an indispensable tool in the learning process, encouraging the acquisition of knowledge in a systematic way. Theory will not be taught, but will develop from knowledge acquired.

Ecoeducation will take place in "educational parks," extensions of museums of science and technology. It will reject the disciplinary approach to education and will unite the physical and human sciences. The age of the "school without walls" will encourage the explosion of quality and awareness, the conquest of inner space, creative learning and free access to knowledge.

Education, like industry, will become holistic. In corporations, for example, it is not enough to combine disciplines to find the "recipe"; rather the task is to learn to combine, integrate and prioritize information flowing from the real world.

This glimpse into the future is sufficiently concrete to discern the end of the power of the teacher and of logical relationships and the beginning of the power of the student and of creativity. People should become aware of their potential before what they learn can limit their

creative freedom. It may, therefore, be necessary to have the courage to burn, in a public auto-da-fé, all the textbooks which explain theoretical questions in a so-called logical sequence, putting the problems of application at the end of the chapter. This is the price that must be paid, the fundamental change that is required - students must be encouraged to think for themselves. Only then will they discover new frontiers.

Teaching should no longer create barriers, however logical in their conception, between human and physical sciences. Teachers will become sources of stimulation, based on their qualities as human beings, rather than being viewed as founts of knowledge. They will be the crossroads.

The Macroscole

The implicit suggestion of this scenario is that science teaching must become holistic. In keeping with the crossroads dialogue, education must cease to be a mosaic of structured disciplines. It must become a Macroscole and teach all disciplines within an overall framework.

The Macroscole has four characteristics:

- the education of people in harmony with their environment; hence the need for stimulation instead of teaching;
- the stimulation of the imagination through the enrichment of concepts and the avoidance of definitions that polarize the learning path; this entails a rejection of textbooks and the initiation of the use of the computer, with its ability to present scientific and human parameters;
- the highlighting of the importance of the relationships between very different disciplines, such as biology and economics, rejecting course compartmentalization and structuring;
- the use of the successive approach, which involves returning to the matter under study several times but at different levels, rather than a linear approach, which consists of learning A in

order to be able to understand B and so on, without ever learning to what use the knowledge can be put. It means the end of linear culture and the birth of the crossroads.

Convergence and Divergence

- *Can the centralized structures of contemporary education survive this type of revolution?*
- *What resources must be added to or substituted for traditional resources?*

A Final Thought

This paper is intended to explore issues rather than propose solutions. It observes the present situation of science teaching and suggests how the future might look. It examines varying degrees of convergence amongst relationships and stimulates the imagination to consider divergent possibilities.

However, the paper would be incomplete if it did not, in addition to the proposed transformations, provide solid arguments in favour of the status quo, stability and security. Charles Clark,[12] one of the great American experts in the field of creativity, has compiled a list of what he terms the "fatal phrases." These are common phrases, that result in the atrophy of imagination and provide good excuses for remaining firmly opposed to new ideas. Perhaps it is worthwhile considering them and adapting them to our individual situations.

"We have never done it like that before
. . . That won't work . . . We don't
have the time . . . We don't have the
manpower . . . It's not in the budget
. . . We have already tried that . . .
We are not ready for that . . . That's
fine in theory but can you put it into
practice? . . .Too academic . . . What
will the students think? . . . Someone
would have suggested it before if it
had been worth anything . . . Too mod-
ern . . . Too old-fashioned . . . We
will discuss that another time . . .
You don't understand our problem . . .
What do the Americans do about this? .
. . We have too many other changes at
present . . . It has worked fine like
that for 28 years, it should be all
right . . . What wild fantasy dreamed
up that? . . . All I know is that it
won't work . . . Let's form a commit-
tee . . . Let's think about this
question for some time and monitor
what happens . . . It's not our prob-
lem . . . The government won't accept
it . . . They will think we're crazy .
. . That won't work here . . . The
students will never accept it . . .
You'll never get management to accept
that . . . Don't go too fast . . .
Let's wait and see . . . The union will
scream . . . We'll get back to that . .
. Let's put it in writing . . . I don't
see the connection . . . That won't
work in our school . . . It's not in
the rule book . . . Nonsense . . .
That's political dynamite . . . It
looks good but I don't think it will
work . . . That's not part of the plan
. . . It's not covered by any of the
regulations . . . We've never tackled a
problem like this before . . . It will
increase the workload . . . That's not
our business . . . Yes, but . . . It
will increase the overall costs . . .
It's too late . . . It's too soon . . .
That will shock people . . . Nothing
will come of it . . ."

APPENDIX

The Profile of the Creative Individual and Techniques for Stimulating Creativity

The findings of a great deal of research have demonstrated that creative individuals share certain common characteristics. Ferrari[13] and Filiatrault[14] have examined all aspects of this question in their works. The essential elements are summarized below.

Intellectual Characteristics

Studies have shown that beyond a certain level, no correlation exists between the degree of creativity and IQ. The important intellectual characteristics of creative individuals include: the conceptual flexibility that enables them to move from frames of reference not obviously connected to each other; the originality which leads them to perceive, react and interpret differently from others (these two characteristics usually involve an abundance of ideas); the preference for complexity, which they regard as a challenge; awareness of a problem, which enables them to identify and define problems quickly; control of creative thought, which enables them to pass quickly from synthesis to analysis, from abstraction to reality, from the unknown to the known, from the hypothesis to the conclusion, from concentration to intuition, and from the conscious to the subconscious.

Personality Traits

Two characteristics underlie the creative individual's personality traits: independence and motivation. Creative individuals are basically inde-

pendent, a characteristic that leads them to defend their ideas passionately when they find themselves in opposition to the majority; to feel different from others and to strive to appear so; to identify authority as a conventional, arbitrary and temporary factor, whose opinion is neither final nor absolute, and whose judgement is valid only as a function of the value of its content; and, to accept, stimulate and express impulses easily. The independence of creative individuals frequently disturbs organizations which cannot cope with it. Nevertheless, the irritation this independence can produce is offset by their motivation to work. Creative individuals are motivated primarily by the tasks at hand and accord greater importance to the nature of their work than to extrinsic rewards such as salary and promotion. Because their thoughts are concerned more with a wider sphere, they will change jobs according to their interests and not interests according to jobs. They are attracted to the initial stages of the decision-making process and take longer to define a problem and generate alternative solutions. In contrast to a frequently expressed prejudice, they are well able to organize work in order to create.

Psychological Traits

Creative individuals are "communicators." Ferrari attributes the following characteristics to communicators: they are voracious but diversified readers; they establish and maintain a large number of relationships with colleagues outside their own departments and organizations; they participate in visits, conferences, fairs and exhibitions; they are essential and natural elements in any communications network; and their natures are easy, open and warm. There are many managers, however, who fear that increasing communications will be to the detriment of sacrosanct efficiency. However, research indicates that the contrary is often true: the more time that engineers or researchers spend in discussion with their colleagues, the more often these discussions take place; and the greater the number of colleagues involved, the greater is their efficiency.

Barriers

Even though senior management in industry and government is aware that creativity results in innovation, a relationship which in turn generates economic growth, creative individuals face many barriers. Economic barriers: the reluctance of corporations to invest real, present resources in individual activities - such as travel expenses - which would enable employees to participate in conferences to glean new ideas. Technological barriers: the fear on the part of management that success may give rise to new problems in the form of possible ensuing accessory technology. Organizational barriers: the hierarchic structure and formal communication channels of organizations which do not take into account that creative individuals function better when they are in contact with a variety of departments. Personal barriers: creative individuals are often in the limelight and offend convention by disturbing normal power relationships. Barriers of perception: defined judgement criteria and rules of action that are normally established to ensure the efficient operation of an organization in a stationary situation rather than to cope with change, the result of creativity. All organizations tend towards stability, whereas innovation causes imbalance; innovation is thus a constant threat to organizational procedures.

Creativity cannot develop behind these barriers, although they can be moderated in a startling fashion by certain common methods. As it would take too long to describe these methods, which are really techniques, we will only briefly outline them below.

Techniques for Stimulating Creativity

Free association techniques:

- brainstorming;
- synectics;
- bionics;
- Delphi method.

Structured techniques:

- check list;
- list of attributes;
- object in focus;
- morphological analysis.

Free Association Techniques

Brainstorming involves a circle within which a problem or a subject is discussed. Because of the freedom this setting provides, individuals can express all their ideas without being subject to criticism. Each individual's ideas act as stimuli for the others, generating, by association, new ideas. The proceedings are recorded or taken down in shorthand.

Synectics is described as "a functional theory designed to make conscious use of subconscious psychological mechanisms which govern every creative activity, developed to increase the probability that a problem will be properly put and properly solved through the knowledge of the mechanisms that must be called into play to arrive at innovative solutions." The principle behind this technique is that creativity is improved if people are aware of these mechanisms. The process consists of making the strange familiar and the familiar strange. It "renews" the individual's perception, especially of such things as personal analogy, direct analogy, symbolic analogy and analogy by fantasy. Synectics differs from brainstorming in that it permits criticism and does not attempt to arrive at a single new idea as the solution to a problem.

Bionics is basically a method of analogy which consists of observing living organisms in nature and deriving natural solutions to apply to human innovations. It is of particular value in fields where technology plays a major role.

The Delphi method is used mainly in futurology. Experts are consulted in a given field and, without bringing them together, a circuit is created among them using a process of continual feedback to arrive at solutions.

Structured Techniques

The check list is used in a systematic way to suggest alternatives or potential solutions. It is based on the fact that the generation of ideas is related to the association of known concepts within an individual's field of perception. Such lists are used commonly by airline pilots, astronauts, architects and engineers.

The list of attributes involves a detailed analysis of a product, service or process, compiled into a list of basic elements or attributes, each one of which is subsequently methodically reviewed using a free association technique.

The object in focus is used primarily to discover alternatives to modify an existing product, service or process, itself regarded as a fixed element with which the elements of the object in focus are associated. The method attempts to answer the question: what effect does object at home A have on fixed element B, considering in sequence all the attributes of A. For example, what is the effect of distance on communications, considering such factors as, for instance, vertical and horizontal distance, time required, distance to be covered, means of transportation and support needed for communication.

Morphological analysis consists of identifying the parameters of a problem and analyzing all the possible interrelationships within them. It is necessary to choose parameters over which some control is possible. This is a structured approach to decision making and problem solving. A problem with four parameters defined by eight flexible characteristics that can be affected would therefore have 4096 possible solutions, one of which might be a unique, original idea.

It is impossible to compare the effectiveness of the various techniques in terms of a specific field of research. There is, nevertheless, one fundamental rule: the technique or techniques which support the research effort must be used.

Convergence and Divergence

- *What are the relationships between the elements of the profile of the creative individual and the objectives of education in geometry, physics, chemistry, geography, English, French, ethics . . .?*

- *Which methods to stimulate creativity are potentially usable in teaching? Are there similarities between them and certain teaching methods?*

NOTES

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